FACTORS AFFECTING NOISE LEVELS OF HIGH-SPEED HANDPIECES

by

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MASTER'S THESIS

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ABSTRACT

Factors Affecting Noise Levels of High-speed Handpieces

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Background: Since the introduction of the high-speed handpiece in 1957, dentists have been concerned about the risk of hearing loss caused by chronic exposure to the high frequencies of the air-turbine motor. Although most studies have reported handpiece noise levels to be within OSHA standards, the literature regarding handpiece-induced hearing loss among dental providers remains equivocal, warranting continued concern. Moreover, handpiece noise may hinder office communication and increase patient anxiety.

Purpose: To determine if three noise-reducing techniques utilized in larger scale, non-dental turbines can be applied to dental handpieces to reduce noise emission without compromising performance.

Methods: Three samples of three brands of high-speed dental handpieces were chosen. Following baseline measurements for speed (rpm) and noise level (dB), the following internal modifications were made sequentially to each handpiece: (1) the bearings were lubricated with a synthetic lubricant (0.5 cc); (2) the internal surface of the head was rotary-polished using a petroleum-based polish; (3) the internal surface of the head was

honed to produce one small channel (0.5mm wide x 0.25mm deep) near the impeller. Mean (± standard deviation) values for each outcome variable (sound level [dB] and speed [rpm]) were calculated for each of the three handpiece models following each treatment. For each outcome variable, mean values were compared via one-way ANOVA ($\alpha = 0.05$).

Results: The three different internal modifications produced no statistically significant improvements in the speed or sound levels of the handpieces.

Conclusions: Treatments should be performed during, rather than after, the manufacturing process to better test the hypothesis.

Clinical Implications: Additional modifications need to be researched to continue to lower the sound levels of handpieces.

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DECS	U.S. Air Force Dental Evaluation & Consultation Service

CHAPTER 1: REVIEW OF LITERATURE

Introduction of the Air-Turbine Dental Handpiece

The high-speed air-turbine handpiece was introduced to improve the efficiency of new diamond and carbide burs (Cherry, Gibbons and Ronaye, 1974; Myers, 1995). Because the new air-driven handpiece was so much faster (capable of bur speeds up to 300,000 rpm, compared to 3,000 rpm with the older electric belt-driven handpieces), it required substantially less hand pressure by the dentist to cut tooth structure. This, combined with the new water spray, reduced the amount of heat and vibration generated at the tooth surface, enabled dentists to complete treatment procedures more quickly, and, ultimately, improved patient comfort and acceptance as compared previous pedal- and electric motor-driven handpieces (Myers, 1995).

However, since the introduction of the Airotor, which is held as the precursor to modern day high speed handpieces, by J.V. Borden and the Dentists' Supply Company in 1957 (Cherry, Gibbons and Ronaye, 1974; Dyson and Darvell, 1993), dentists have expressed concern over the possible risk for hearing loss. One of the first warnings came from Mittelman (1959), who, in an editorial to the Journal of the American Dental Association, voiced concern about the health hazard caused by chronic exposure to the whine of the turbine. His main concern was that the frequency of the handpiece may cause hearing loss over a period of time. He recommended periodic hearing tests over time to assess for hearing loss. In 1961, Kessler suggested that hearing loss may cause confusion, fear, and loneliness, and that sometimes hearing loss is accompanied by dizziness, which would be a handicap in the practice of dentistry. In the years since these initial warnings, there have been conflicting reports in the scientific literature regarding

the effects of handpiece noise on hearing loss among dental practitioners. Undoubtedly because handpiece noise levels generally fall below acceptable limits (Leonard and Charlton, 1999; Lehto, 1990; Sorainen and Rytkonen, 2002; Bahannan and colleagues, 1993), manufacturers have done little to reduce these noise levels further. Rather, improvements have fallen into two categories: convenience (fiber optics and push button chucks) and performance (increased speed and torque) (Dyson and Darvell 1993). Reducing dental handpiece noise levels may be beneficial for both providers and patients; however, few studies have advocated or attempted to implement specific measures to accomplish this.

Characteristics of Sound

Sound is an alteration in pressure, particle displacement, or particle velocity which is propagated in an elastic medium (Olson, 1967). By this definition, sound is produced whenever air is set into motion by any means. Sound travels as a wave and is characterized by the following properties: frequency, wavelength, wavenumber, amplitude, sound pressure, sound intensity (volume), and speed or velocity (Table 1) (Olson, 1967). The volume and frequency of a sound, when combined with a length of exposure (time), are the factors that affect hearing loss (Bahadori, 1993).

Table 1. Characteristics of sound waves.

Property	Definition	Unit of Measurement	Calculation
Frequency (f)	The number of recurrent waves or cycles which pass a certain observation point per second	Hertz (Hz); Cycles per second	frequency f is equal to the phase velocity (v) of the wave divided by the wavelength (λ) of the wave: $$f = \frac{v}{\lambda}.$$
Wavelength (λ)	The distance the sound travels to complete one cycle; the distance between consecutive corresponding points of the same phase, such as crests, troughs, or zero crossings	Centimeters (meters, millimeters, etc.)	$\lambda = v / f$
Wavenumber (k)	The sound waves spatial frequency.	Reciprocal length (m^{-1}, cm^{-1})	$k = 2\pi \ / \lambda$
Amplitude	The magnitude of change in the oscillating variable with each oscillation of a sound wave		$x = A\sin(t - K) + b$, A is the peak amplitude of the wave, x is the oscillating variable, t is time, K and b are arbitrary constants representing time and displacement offsets, respectively.
Pressure	A sound wave consists of pressures above and below the normal undisturbed pressure in the gas	Dyne/cm^2	$p_{total} = p_0 + p_{osc}$ where: p_0 = local ambient atmospheric (air) pressure, p_{osc} = sound pressure deviation.
Intensity (Volume)	Sound energy transmitted per unit of time in a specified direction through a unit area normal to this direction at the point	Decibels (dB)	
Speed (Velocity) (v)	The finite distance traveled by of the sound wave in a unit of time	cm/sec	In air: $C = 33{,}100\sqrt{1{+}0.00366t}$ Where t is the temperature in centigrade.

Brief History of Hearing Loss and How it is Measured

Audiology is the branch of science that studies hearing and balance; it is concerned with not only the function of the ear, but also with related diseases and disorders. Audiology considers the ears as an "aid to life." Since the formal introduction of audiology as a recognized health care profession in 1946, it has developed a wealth of knowledge. The field of audiology is governed by the American Speech-Language-Hearing Association. Clinical audiologists test hearing and make recommendations concerning the use and types of hearing aids to patients (Davis 1960). The first audiometer arrived at the Mayo Clinic in 1930 (Olsen, Rose, and Hedgecock, 2003). An audiometer is an instrument used to perform an audiogram, which is a test in which the subject listens to a series of pure test tones that differ in intensity and frequency. The subject then indicates the points at which the sounds were heard. These points are plotted on a chart which is called an audiogram. With the audiogram, the overall hearing acuity of each ear can be determined and compared over time to assess hearing loss (Kessler 1961, Durrant 1995).

Hearing Loss Among Dentists

Taylor, Pearson and Mair (1965) were the first to report evidence suggesting that dental handpieces may cause hearing loss. The authors compared the hearing acuity of age-matched dentists (n = 40) and high school teachers (n = 29). Subjects who reported previous exposure to loud noises, such as guns, were excluded from the study; this reduced the original number of dental practitioners in the study from 70 to 58. The number was further reduced by seven, having a history of ear disease, and 11, not using pneumatic handpieces, leaving a total of 40 dentists eligible for the study. An audiogram

was conducted on each subject. As compared to the teachers, the dentists exhibited statistically significantly poorer hearing in the 4000 – 6000 Hz range. The differences between the groups were 9.1 dB for the left ear and 5.9 dB for the right ear.

Weatherton, Melton, and Burns (1972) compared students to instructors at the University of Tennessee College of Dentistry. Participants were divided into three groups based upon age and exposure to handpiece noise. The first group consisted of ten first-quarter students with a mean age of 22.4 years; the second consisted of ten twelfth-quarter students with a mean age of 24.3 years; and the final group consisted of ten faculty members with a mean age of 40.7 and an average time in practice of 15.3 years. Their results showed no differences in hearing between the first- and twelfth-quarter students; faculty members, however, demonstrated markedly poorer hearing in the 4000 – 6000 Hz range when compared to the students. To ensure that this hearing loss was not due to aging (presbycusis), the authors compared the faculty group to a non-dentist population of the same age. This comparison showed a statistically significant difference between the non-dentist population and the dental faculty.

In contrast, Forman-Franco, Abramson, and Stein (1978) found no hearing loss among a group of 70 dentists when they were compared with an age-adjusted non-dentist population. The dentists were from eight different specialties; mean ages ranged from 35 to 50.5 years. Each dentist was given a questionnaire to determine noise exposure levels. Each was then given a hearing test and the results were age-adjusted and compared to the non-dentist population. They actually found that, in the 45-64 age range, the dentists had better hearing in the 3000, 4000, and 6000 Hz ranges.

Zubick, Tolentino, and Boffa (1980) compared the hearing of 137 dentists (111 general dentists and 26 specialists) to 80 physicians. Each group was given a questionnaire to gain information on age, right- vs. left-handedness, previous history of ear disease, exposure to noise other than that related to the dental handpiece, dental specialty, year graduated from medical or dental school, and estimated time of exposure to handpiece noise per day. The average age of the groups was reported as 47.6 years for the dentists and 45.3 years for the physicians. The physicians had a better hearing threshold or sensitivity (i.e., the sound level, in decibels, below which a person's ear is unable to detect any sound), especially in the 4000 Hz frequency range, which is at the high point of the range of the human voice. Upon analysis of the data, the researchers also noticed that the left ears of the right-handed dentists were affected more severely than the right ears; however, they did not document if the same was true for left-handed dentists. This difference was not noted in the physicians, which may implicate the handpiece as a possible cause of the hearing loss. Further, the authors noted that the dental specialists also had a marked hearing loss that was comparable to that of the non-specialists. This led them to suggest that the noise exposure during dental school or prior to postgraduate education may be a factor.

Man, Neuman, and Assif (1982) sent questionnaires to 250 dental practitioners referred to as "engaging mainly in general dentistry" to assess daily handpiece noise exposure; 175 were returned. Based upon the practitioners' estimates, the surveys revealed that the average daily exposure was 15 minutes. The authors then made recordings and measurements of frequency and decibel levels of a handpiece running free and while cutting extracted teeth. These recordings were played back to 20 subjects for

15 minutes to simulate a “typical” daily exposure. The subjects had hearing tests performed before and after the exposure. No hearing loss was noted. However, several shortcomings are noteworthy in this study. First, the average daily exposure of 15 minutes seems quite low for a general or restorative dental practice. This may be a function of the profile of the survey participants in this study; however, the authors did not describe the practice characteristics of the participants. Therefore, the exposure time reported may not be typical of a larger group of general practitioners. Second, the simulated exposure of 15 minutes was applied continuously, rather than intermittently, as would typically occur throughout the day in practice. Finally, hearing tests were performed after only one 15-minute exposure. The results (i.e., no hearing loss) are not surprising; however, the overall study design does not reflect the handpiece noise exposures one might reasonably expect to find in a typical general practice.

Hyson (2002) reviewed nineteen articles that studied hearing loss among dentists. Some of the studies found statistically significant differences in the hearing loss among dentists as compared to the general population, while others did not. Because of the inconclusive results of the studies, he recommended further research on the topic, but made no suggestions of action for clinicians to follow concerning hearing protection or evaluation.

Gijbels and colleagues (2006) tested the hearing of 13 first year Flemish dental students and then tested the same group 10 years later. They found a statistically significant hearing loss in the left ears of the subjects. Hearing in the right ears was unchanged. The authors offered no explanation for their findings. One possibility may have been the proximity of the dental handpiece to the affected ear (i.e., whether the

subjects were right- or left-handed); however, that information was not reported. It was noted that as the sound frequency increased, so did the extent of hearing loss (i.e., beginning at 12 kHz, hearing loss increased linearly with increasing sound frequencies).

Similarly, Bali and colleagues (2007) reported a hearing loss among dental students even after one day in the clinic. The amount of time spent in the clinic and the procedures performed, i.e. the type and extent of noise exposure, were not specified. They evaluated 32 dental students with a mean age of 26 years (range = 20-30 years). The subjects were tested in the morning before clinic hours and again after clinic hours on the same day. They found statistically significant changes in the 4000 – 6000 Hz range for the left ear and 6000 Hz for the right ear. The mean decreases were 2.7 dB at 4000 Hz and 3.0 dB at 6000 Hz in the left ear, and 3.0 dB at 6000 Hz in the right ear. The authors' stated that although the change is small, it is not negligible and that longitudinal studies should be done in three-year intervals. Perhaps more importantly, the results demonstrated that even short-term noise exposure may result in at least transient measurable hearing loss; however, the subjects were not tested again at a later date to determine if the hearing loss was temporary or permanent. Another limitation of this study is that the students were not compared against a non-dentist population to determine if degradation of hearing acuity over the course of the day is a normal occurrence.

OSHA Guidelines

The Occupational Safety and Health Administration (OSHA) allows exposure to noise levels based upon the volume (in decibels) and length (in hours) of exposure (Table 2); the higher the volume, the lower the allowed time of exposure without hearing

protection. “When employees are subjected to sound exceeding [those listed in Table 2], feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels to within [the levels of Table 2], personal protective equipment shall be provided and used to reduce sound levels to within acceptable levels (OSHA 1910.95(b)(1)).” OSHA uses a conversion chart that shows equivalent decibel levels based on the frequency of the noise (Figure 1).

Table 2. OSHA standards for allowable noise exposure (www.osha.gov).

Decibel Level	Time of exposure allowed without protection
90dB	8 Hours
92dB	6 Hours
95dB	4 Hours
97dB	3 Hours
100dB	2 Hours

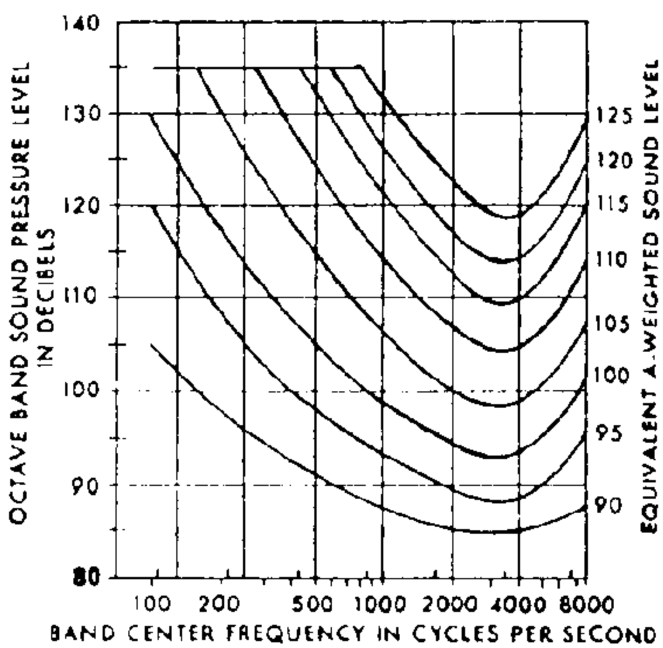

Figure 1. Equivalent sound level contours. (http://www.osha.gov/OshStd_gif/10gfg_9.gif)

Dental Handpiece Noise Levels

The intensity (dB) of noise is directly proportional to the risk and the rate of hearing loss. For example, the noise level inside an automobile interior is 60-92 decibels, a lawn mower is 80-95 decibels, and a power saw is 95-110 decibels (Bahadori, 1993). Bahannan and colleagues (1993) measured noise levels from new handpieces and found that the levels were below the OSHA standard of 90 dB for an 8 hour day (Table 2). The sound was measured 5 cm from the operator's ear at a 45 degree angle. The authors also found that noise levels measured during cutting (78.98 dB) were significantly higher than without cutting (66.84 dB). Similarly, Kam (1990) measured decibel and frequency levels in a dental office for an eight-hour day. The measurements were taken within 18 cm from the practitioner's ear. His results showed an average noise level of 91 dB (range = 81 – 112 dB) and a mean frequency of 6000 (±2000) Hz.

Leonard and Charlton (1999) evaluated the noise levels of nine commercially available high-speed handpieces at baseline and after 250, 500, 750, and 1000 simulated cycles of use and sterilization. Decibel measurements were made 18 inches from the head of the handpiece. They determined that the handpieces produced between 69.4 dB and 77 dB and that the decibel level decreased over time for all models.

Barek, Adam, and Motsch (1999) performed a large band spectral analysis on three brands of dental turbines (n = 17). They made ten recording of each turbine without the use of burs. They then took three samples each of two brands and performed 10 recordings with idle rotation and during enamel cutting on recently extracted teeth. The spectral analysis was performed for frequency and amplitude. They found that the handpieces produced between 101 and 115 dB and frequencies of 5.6 ± 0.73 kHz, 20.1 ±

2.16 kHz, 35.7 ± 2.56 kHz, and 46.5 ±0.71 kHz. The range of frequencies was given without the specifics of which testing methods produced what frequencies.

Altinoz, Gokbudak, Bayraktar, and Belli (2001) measured the frequency of five high-speed handpieces under eight different working conditions. These included free working conditions without burs, and with fissured, flare, round, and inverted cone burs; under load they were tested with fissured burs and applied to the surface of a block of composite, a block of amalgam, and the occlusal surface of an extracted molar. A total of forty measurements (n = 5 for each working condition) were made at 30 cm away from the handpiece and analyzed by computer software for frequency. The frequencies of the handpieces ranged from 4,648 Hz to 11,988 Hz with a grand mean of 6860.2 Hz; no statistically significant differences in mean handpiece noise levels among the eight working conditions were reported.

Wilson, Vaidyanathan, Cinotti, Cohen, and Wang (1990) measured the noise from five different handpieces. Each handpiece was operated with seven different burs while drilling on three different materials commonly used in dental procedures: ceramic, amalgam, and a high silver alloy. The measurements were taken 30 cm from the handpiece head. Noise levels ranged from 48 to 90 dB. They then tested for speech intelligibility. This was done by adding 12 dB to typical speech levels in the 250-4000 Hz range and subtracting the octave-band sound levels. They then measured the number of nonsense syllables and sentences that could be understood upon first presentation. Forty-eight percent of nonsense syllables and 90 percent of sentences were able to be understood on the first attempt while diamond burs were being used; when carbide burs

were used, understanding of nonsense syllables and sentences decreased to 33 percent and 77 percent, respectively.

Sorainen and Rytkonen (2002) recorded 7000 one-second samples of handpiece noise while a dentist treated seven patients. A microphone was placed 1.2 meters from the patients' mouths; in addition, they recorded 150 one-second samples from 16 handpieces in a laboratory setting at a distance of 0.3 meters. The authors then analyzed the recordings for frequency and decibels. While treating the patients, the average sound levels were 76 dB, with highs occasionally over 85 dB. The frequency ranged from 25-80,000 Hz, with the noise being the most powerful (74 dB) in the 40,000 Hz octave band. Similarly, in the laboratory tests, the frequency range was 25-80,000 Hz, with the most powerful noise levels (83 – 89 dB) again in the 40,000 Hz octave band.

Lehto (1990) conducted a multifaceted study on the noise from handpieces and the hearing of dentists. The first aspect measured handpiece noise in a dental operatory over a four- hour 50 minute period while 12 patients were being treated; a radio was turned on for half of the time. Measurements were taken at ear level of the dentist and also attached to the collar; only one brand of handpiece was used. The noise level was measured at 65 dB. Next, five handpieces of varying wear, maintenance conditions, and of different generations were measured, in a laboratory, for frequency at a distance of 25 cm. He found the noise level to be between 68 and 78.6 dB, with a handpiece exhibiting badly worn bearings producing the loudest noise and highest frequency. He also found that the newer generation handpieces from the 1980's were just as noisy as the handpieces from 1968. He then compared the audiograms from 46 dentists (age range 33 – 42 years) who were tested in 1973 to those of 56 dentists tested in 1988. All of the

dentists who participated in the original study in 1973 were invited to attend the study in 1988, but the author made no notation about how many of the original group participated. Comparing the audiograms from 1973 and 1988, he found a statistically significant decrease in hearing threshold at the 6000 Hz frequency, but attributed this to differences in calibration from the earlier exams and the use of different headphones from the previous audiograms. Lehto also included data from a 1990 survey of 93 dental practitioners. He reported that 68% of men and 79% of women practitioners perceived some disturbance by noise in the dental work environment; however, he did not provide the details of the disturbances or their effects. He concluded with the statement, "Dental drill noise is not and has never been a risk to dentists' hearing."

There are two types of hearing loss: (1) hearing loss associated with exposure to high- volume and/or high-frequency sounds ("conductive" or "noise-induced" hearing loss); and (2) hearing loss associated with aging (presbycusis) (Coles 1985). High-frequency sensorineural hearing loss occurs at frequencies above 4000 Hz if the high decibel level and excess time requirements are met (Coles 1985). The two factors, noise level and time, are related in an equal energy principle. This states that equal amounts of noise energy totaled over time cause equal amounts of hearing loss (Coles 1985). Hyson's (2002) review of the literature suggested that dentists are exposed to handpiece noise from 12 to 45 minutes per day. Another study (Kam, 1990), however, reported that the exposure was from 109 to 115 minutes, based upon measurements of the amount of time that high speed handpieces were operated in a two-provider dental office for an eight hour day. Although Kam measured noise levels for only one day, actual measurements were taken in a dental office. In contrast, the study by Man and colleagues (1982), which

reported an average daily exposure of only 15 minutes, was accomplished by a survey asking general dentists to estimate their daily exposure. The actual measurements by Kam (1990) seem to be more accurate than the surveyed estimations by Man and colleagues (1982). However, all levels are below OSHA standards for a hearing conservation program. The OSHA standards for a hearing conservation program (OSHA 1910.95(c)(1)) are listed in Appendix A as follows: The employer shall administer a continuing, effective hearing conservation program, as described in paragraphs (c) through (o) of this section, whenever employee noise exposures equal or exceed an 8-hour time-weighted average sound level (TWA) of 85 decibels measured on the A scale (slow response) or, equivalently, a dose of fifty percent (OSHA 1910.95(c)(1)).

Effects on Dental Patients

Regardless of the effect on practitioners' hearing, the sound created by air-turbine handpieces can be disturbing to dental patients. Willershausen, Azrak, and Wilms (1999) investigated the effects of fear of dental treatment on oral health in adults with a mean age of 42 (± 16 years), with 41% under the age of 35. Of their 59 subjects, 38 (65%) reported some level of fear of dental treatment. Thirty-one found the sound of the handpiece to be unpleasant. This is second only to feeling the vibration from the handpiece. Overall comparison of the DMFT (Diseased/Missing/Filled Teeth) index values among the patients questioned showed no significant correlation between this value and fear of treatment. However, when analyzed by age groups, the data revealed that patients younger than 35 did show a significant increase of DMFT values. Moreover, 14% of the patients reported canceling or failing their dental appointments due to fear.

Sources of the noise emitted by dental handpieces.

To discover which components of the dental handpiece may contribute to the noise produced, a search of the engineering literature was completed. This review suggests the noise may emanate from the bearings and/or the flow of air over the impeller blades (Sweetland, Grabowska, Sekularac, and Roby, 2010; Mann, McKee and Zlatic, 2001, Church and Gordon, 1995). Factors that affect the bearing noise are classified as internal and external (Jayaram and Jarchow, 1978). Internal influences are manufacture inaccuracies causing lobing (out of round), waviness, and surface roughness of the bearings. Any of these factors can increase wear and vibration of the bearings, which, in turn, increase the noise level. If the bearings are not installed properly, these defects can also occur over time because of trapped dirt and dust causing increased friction and vibration. External parameters include operating speed, the supported load, and the viscosity of the lubricant (Jayaram and Jarchow, 1978). The noise level increases progressively with speed; however, a saturation speed exists, above which no increase in noise occurs. The noise level also increases slightly with load and decreases significantly with an increase in the viscosity of the lubricant (Jayaram and Jarchow, 1978).

Several techniques have been applied to the typical large scale (non-dental) turbine design to help them work more efficiently and with less noise. These include the following: (a) porting, removing sharp turns in the path of the air flow by beveling angles, (b) polishing the internal aspect of the turbine housing to allow for a less turbulent path for the air flow, and (c) manufacturing diffusing vanes in the turbine housing to better direct the air flow (Sweetland and colleagues, 2010; Mann and colleagues, 2001; Church and Gordon, 1995). We have found no current manufacturer claims regarding

utilization of such design features to reduce dental handpiece noise levels. It is quite possible that the size of the current generation of high-speed dental handpieces makes it difficult to accomplish the modifications produced in larger manufacturing processes. However, Kavo America (Lake Zurich, IL) claims to have reached a noise level of 57 dB with a "precision-balanced turbine" in its handpiece.

Summary

Air-turbine handpieces emit sound and, despite concerns, these noise levels have been reduced only slightly since the introduction of the high-speed dental handpiece. High levels of noise have the potential to hinder communication, increase patient anxiety, and damage hearing. Dental handpiece manufacturers have incorporated certain design features to improve handpiece efficiency and reduce noise levels; some of these include the use of smaller bearings and changing the impeller design (Myers 1995). However, little progress has been made in the reduction of the handpiece noise. Although dental handpiece noise levels are within OSHA standards, they remain noticeable to both providers and patients. Moreover, although the literature regarding handpiece-induced hearing loss among dental providers is equivocal, some level of concern remains valid. Air-driven handpieces remain the gold standard in dental practice; however, some measurable reduction in noise level output would, undoubtedly, be welcomed. Are there additional aerodynamic features that can be incorporated into the current design of turbine handpieces that might reduce the noise level? Therefore, the purpose of this study is to see if modern noise-reducing techniques that have been applied to larger scale, non-dental turbines can be applied to the turbines in dental handpieces to reduce noise emission without compromising performance.

CHAPTER II: MATERIALS AND METHODS

For this laboratory evaluation (pilot study), we chose to evaluate three currently available air-turbine high-speed handpieces: Midwest Tradition, Kavo POWERtorque LUX 635B, and Lares 757 (Table 3). These models were selected from the list of handpieces that have been evaluated and recommended for government purchase by the U.S. Air Force Dental Evaluation & Consultation Service (DECS) based upon their noise ratings (one from each category. DECS breaks the noise categories down into (+) positive, (-) negative, and (0) neutral (http://airforcemedicine.afms.mil).

Table 3. List of dental handpieces evaluated.

Handpiece	Manufacturer	Mfg Recommended Air Pressure	DECS overall rating (Noise rating)
Tradition	DENTSPLY Midwest 901 West Oakton Street Des Plaines, IL 60018-1884	30 psi	Marginal (-)
POWERtorque LUX 635B	Kavo America 340 East Main Street Lake Zurich, IL 60047	34 psi	Recommended (+)
Lares 557	Lares 295 Lockheed Avenue Chico, CA 95926	32 psi	Neutral (0)

We purchased three samples of each handpiece. The handpieces underwent baseline evaluation for sound level (dB), frequency (Hz), and speed (rpm). The sound level and frequency were measured to see if the handpieces can be made quieter by internal modifications. The speed was measured to determine if any of the modifications affected the performance of the handpiece. The handpieces were run at the manufacturers' recommended air pressures in a temperature- and humidity-controlled room. Sound and frequency measurements were taken at a distance of 18 inches from the handpiece. The sound level was measured using an Extech 407750 sound level meter (Extech Instruments, 9 Townsend West, Nashua, NH 03063). Frequency (Hz) and speed (rpm) were measured using an HPW-2 Handpiece Counter (Micron Corporation, 1-34-14 Higashiyukigaya, Ota-ku Tokyo 145-0065, Japan).

The following internal modifications were made sequentially to each handpiece (Table 4). Sound, frequency, and speed measurements were conducted following each treatment, as described for the baseline tests above.

Group A: The bearings were lubricated with a synthetic bearing lubricant (Mobil 1, part number 98DM91). Each bearing was packed with 0.5 cc of the lubricant measured from a 3-cc syringe. Following test measurements, the lubricant was removed with handpiece cleaner and the bearings lubricated with the respective manufacturer's recommended lubricant (i.e., returned to manufacturers' specifications).

Group B: The internal surface of the handpiece head was polished using a petroleum-based polish (Mothers Billet Metal Polish, part number 05106; Mothers, Inc., Huntington Beach, CA), and cotton tipped applicators in a slow speed straight handpiece at 2000 rpm for 1 minute.

Group C: The internal surface of the handpiece head was honed to produce small channels similar to the patents discussed in the literature review. The back cap and the turbine were removed. A piece of light cure acrylic was placed over the back of the handpiece. A whole was cut in the acrylic. A half round bur was notched so that the head of the bur would reach the drive air tube. The notch was used as a guide on the acrylic cap. One channel was cut to the depth of the half round bur from the drive air tube to the exhaust tube.

Table 4. Handpiece treatment groups.

Treatment Group	Procedure	Technique
A	Synthetic bearing lubricant	0.5 cc
B	Internal polish	Mother's Metal Polish; 1 minute @ 2000 rpm
C	Internal honing	Modified head reamer

Statistical analysis. Mean (± standard deviation) values for each parameter (sound level [dB], frequency [Hz], and speed [rpm]) were calculated for each of the three handpiece models following each treatment (A – C), Results were analyzed via one way analysis of variance (ANOVA) and, when indicated, Tukey HSD post hoc tests. Statistical analyses were accomplished using Statistical Package for the Social Sciences (SPSS) Version 18 computer software (SPSS, Inc., Chicago, IL). All significance levels were set at $\alpha = 0.05$.

CHAPTER III: RESULTS

Results of the study are listed in Table 5.

Table 5. Mean (± standard deviation (SD)) handpiece speed (rpm) and noise levels (dB) at baseline and following three treatments (n = 3).

	Handpiece					
	Kavo		**Midwest**		**Lares**	
RPM	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Baseline	416.9667	5.25959	427.9333	13.10509	376.0667	6.76560
Grease	394.3333[a]	5.22717	408.8333	2.37978	375.5000	3.25115
Polish	425.7333	5.71343	423.4333	14.30047	384.6667	2.37136
Hone	415.1333	8.16354	393.8667[b]	6.78552	360.3667	10.66130
dB at 1cm	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Baseline	72.5667	1.85023	85.5333	2.08407	82.1000	4.49778
Grease	75.1333	5.41695	85.2667	.83865	75.0000	4.74658
Polish	74.4667	5.47205	87.1667	1.65025	80.2667	2.45832
Hone	71.3667	1.15902	82.7000	4.55082	74.0333	4.53468
dB at 18 inches	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Baseline	59.6667	1.26623	59.6667	1.26623	67.9333	4.44560
Grease	60.5333	.45092	60.5333	.45092	66.9000	6.08276
Polish	59.0000	.87178	59.0000	.87178	62.7667	3.15013
Hone	61.1000	1.22882	61.1000	1.22882	65.3667	3.98037

* One-way ANOVA and Tukey HSD ($\alpha = 0.05$). For each handpiece, no significant differences within each treatment group, except: [a] = 0.009, [b] = 0.016

The average for the baseline RPM of the Kavo was 416,900 with a decibel level of 72.6 at 10mm and 59.7 at 18 inches. With the application of the lubricant the RPMs fell and the sound level increased at 10 mm at 18 inches. After the internal polish the RPM rose above the baseline but the decibel level rose at 10 mm but fell at 18 inches. After the honing the RPMs fell and the decibel levels fell at 10 mm but rose at 18 inches. The only change that was statistically significant was the RPM drop after the application of the lubricant (0.009).

The average for the baseline RPM of the Midwest was 427,900 with a decibel level of 85.5 at 10mm and 65.9 at 18 inches. With the application of the lubricant the RPMs fell and the sound level decreased slightly at 10 mm but rose at 18 inches. After the internal polish the RPM decreased and the decibel level rose at 10 mm and at 18 inches. After the honing the RPMs fell and the decibel levels fell at 10 mm and at 18 inches. The only change that was statistically significant was the drop in RPM in the hone group ($p = 0.016$).

The average for the baseline RPM of the Lares was 376,100 with a decibel level of 82.1 at 10 mm and 67.9 at 18 inches. With the application of the lubricant the RPMs fell and the sound level decreased at 10 mm and at 18 inches. After the port and polish the RPM rose, the decibel level fell at 10 mm and at 18 inches. After the honing the RPMs fell and the decibel levels fell at 10 mm but rose at 18 inches. There were no statistically significant changes from the baseline to the other measurements for RPM or sound levels at either distance.

CHAPTER IV: DISCUSSION

The baseline readings fell within the expected range based upon the literature review. However, with the application of the synthetic lubricant to the bearings, it was expected that the speed and the noise level would decrease. A decrease in the speed was seen, but there was no change or a slight increase in the sound level. When the handpieces were first run after the application of the lubricant, it took 20 to 30 seconds for the excess lubricant to be expelled and the handpieces to reach operating speed. After the turbines were removed, lubricant was visible inside of the head of the handpieces and also in the exhaust tubing. It is possible that this remaining lubricant impeded the airflow, preventing a decrease in the noise level and sometimes causing additional turbulence, and, therefore, increasing the noise level slightly.

Workshop chatter suggests that internal combustion engines can receive approximately a 10% power increase from internal polishing by an experienced technician. In the case of the handpieces, there was an expected gain in RPM, but with it came an increase in sound level. This is also expected until the bearings reach the sound saturation level, above which no further increase in speed can increase the sound level. With the handpieces and the limited experience of the technician performing the experiment, we saw a gain of only a little over 2% for each of the brands of handpieces. In the hands of an experienced technician, higher gains may be expected, but also with an increase in the sound levels.

The honing of the inside of the head of the handpieces achieved mixed results in both the speed and noise measurements. We believe this is because the methods selected relied solely upon the hand skills of the technician performing the modifications. If the

incorporation of diffusing vanes could be added to the manufacturing process, we speculate that a more significant drop in sound levels might be achieved without a decrease in performance.

Limitations of this study begin with the application of the lubricant to the bearings. The higher priced Midwest and Kavo handpieces are shipped with shielded bearings, which help to prevent dirt and other debris from getting access to the ball bearings. This makes it more difficult to place the thicker lubricant into the ball bearings. It is possible that the bearings were not fully packed with lubricant; without being about to be able to visualize the bearing chamber, we were unable to tell. The alternate of the shielded bearings can be seen with the Lares handpieces having non-shielded, open bearings and the ability to visualize a fully packed bearing, we saw a decrease in sound levels, which was not the case for the Kavo and Midwest handpieces.

Limitations for the internal polish include the experience level of the technician and the unknown thickness of the drive air and exhaust tubing. As stated earlier, a more experienced technician might produce a much faster RPM. The unknown thickness of the drive air and exhaust tubing requires that the polishing be more conservative to prevent puncturing the tubing, which would render the handpiece useless; because the number of available samples was quite limited, we were particularly cautious in performing this modification. A more aggressive polishing may have resulted in a higher performance gain.

The honing limitations included the hand skills of the technician as well. Moreover, the thickness of the handpiece head limited the depth of the grooves not allowing proper diffusion of the airflow. If the diffusion vanes could be manufactured

into the head of the handpiece, a more desirable result might be achieved. However, this is limited by the ability of the manufacturers to produce the vanes on a much smaller level as compared to traditional industrial-sized turbines.

Electric handpieces can be considered as an alternative due to the reduction of noise. Kavo reports a sound level of 55dB for its electric handpiece. However, the cost and size are much greater than that of conventional pneumatic handpieces. I telephoned technical support at Kavo USA to get the specifications on their most current generations of both the electric and pneumatic handpieces. I also priced both on a popular dental supply company website. The current price of a Kavo electric handpiece system with the motor and one handpiece, is approximately $2,900.00, with additional handpieces costing approximately $1,500. The pneumatic Kavo handpiece costs slightly less at $1,300.00. The electric and pneumatic handpieces are very similar in length, 162 mm and 173mm respectively; however, the electric weighs twice as much (141g versus 71g).

CHAPTER V: CONCLUSION

Under the conditions of this study, none of the three internal modifications effectively reduced the noise levels emitted by three brands of high speed dental handpieces. Had this project produced statistically significant results, the modifications attempted might have provided feasible methods for manufacturers to decrease the noise of dental handpieces, which could, in turn, reduce the risk of hearing loss among dental practitioners, reduce operatory disturbances, and also help reduce anxiety among dental patients.

The thick lubricant is not an option for high speed dental handpieces. The high viscosity of the lubricant does not allow the turbines to reach proper speed; this was evident in the amount of time required for the handpieces to reach operating speed, only after the majority of lubricant was discharged through the head of the handpiece.

Internal polishing produced a marginal gain in performance, but with an increase in noise levels, which is counterintuitive of this investigation. Compared to the baseline, all brands of handpieces were faster after the polishing than the original highspeed handpieces; however, the increase was statistically significant for only ???. Even though the honing produced a reduction in the speed, without the reduction of the noise levels, they performed at the same level of highspeed handpieces. This should be researched further, in the manufacturing process, with better (e.g., automated) equipment, during the manufacturing processes.

High speed air-driven dental handpieces are noisy. At a distance of 18 inches (the average distance at which most dentists use their handpieces), noise levels fell below the OSHA-mandated minimum safety levels for occupational exposure. However, at a

distance of 10 mm, all three handpieces exceeded the OSHA threshold limit. Regardless of any potential safety issues, many dentists and patients find this noise distracting. Until the dental equipment manufacturing industry has the technology to make electric handpieces as small, light, and inexpensive as pneumatic handpieces, there should be conscious efforts made to reduce the noise of pneumatic handpieces.

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